Gamma-Ray Bursts

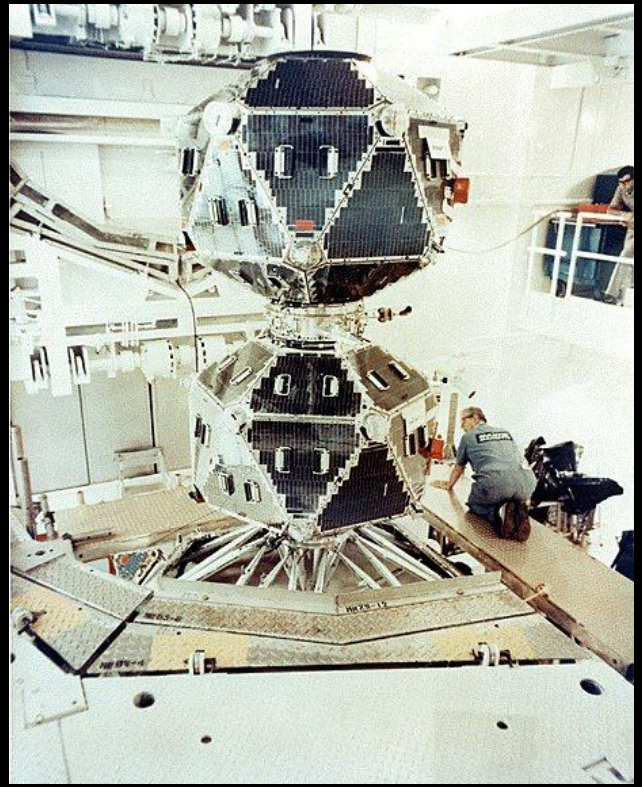
A Story of the Biggest Explosions in the Universe, and the last ‘Great Debate’ in Astrophysics

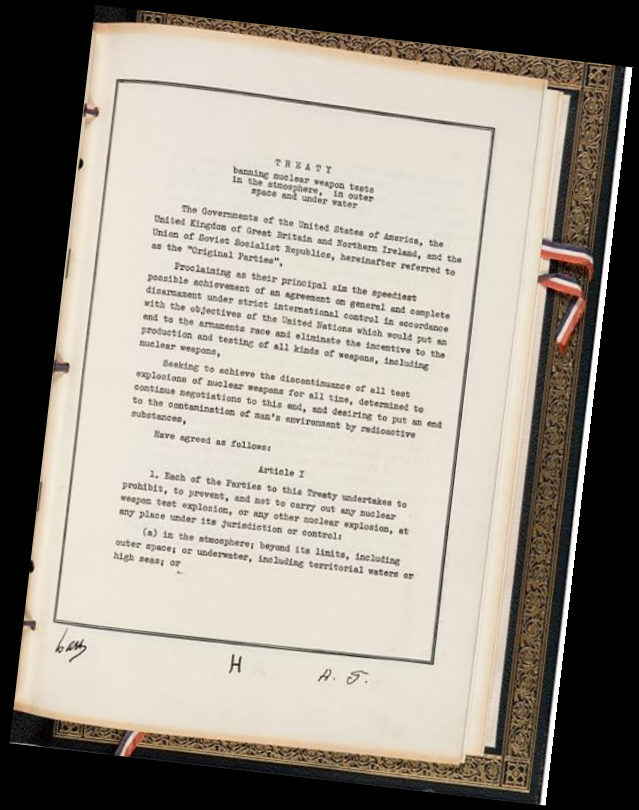
Drew Lapeer
AoT Western Mass.

Chapter One

The Cold War, Nuclear Testing, and the First GRB Detections

1963: Nuclear Test Ban Treaty





TREATY
banning nuclear weapon tests
in the atmosphere, in outer
space and under water

The Governments of the United States of America, the United Kingdom of Great Britain and Northern Ireland, and the Union of Soviet Socialist Republics, hereinafter referred to as the "Original Parties",

Proclaiming as their principal aim the speediest possible achievement of an agreement on general and complete disarmament under strict international control in accordance with the objectives of the United Nations which would put an end to the armaments race and eliminate the incentive to the production and testing of all kinds of weapons, including nuclear weapons,

Seeking to achieve the discontinuance of all test explosions of nuclear weapons for all time, determined to continue negotiations to this end, and desiring to put an end to the contamination of man's environment by radioactive substances,

Have agreed as follows:

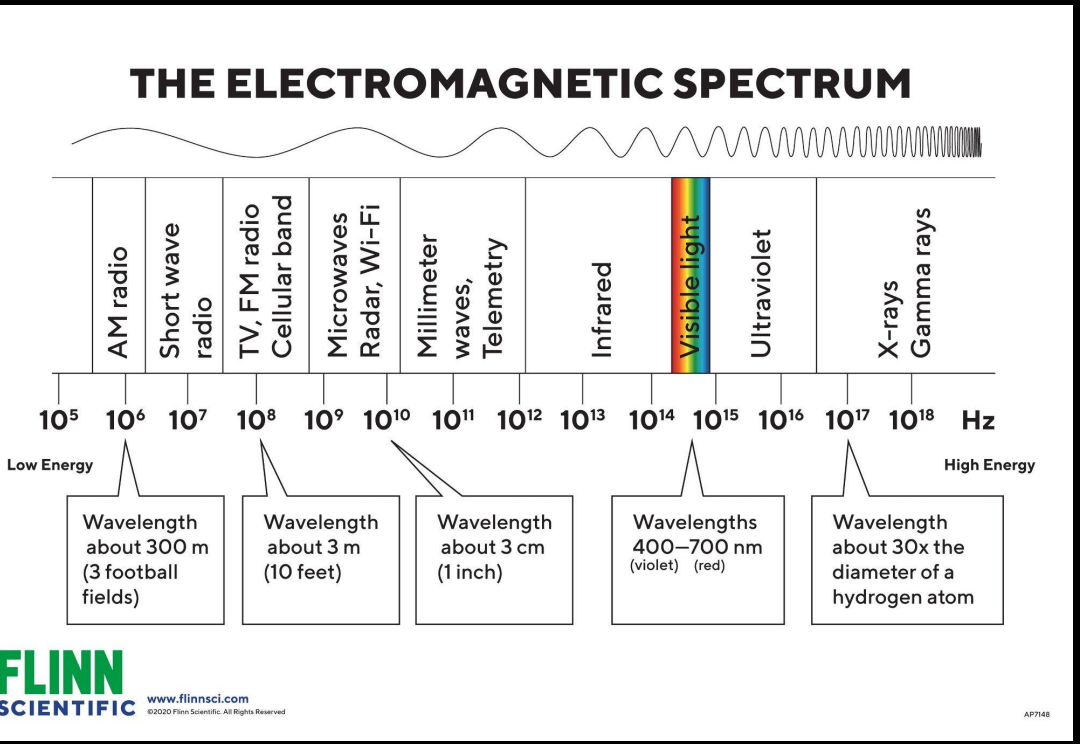
Article I

1. Each of the Parties to this Treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control:

(a) in the atmosphere; beyond its limits, including outer space; or underwater, including territorial waters or high seas; or

H

A. G.


THE ELECTROMAGNETIC SPECTRUM
AM radio
Short wave radio
TV, FM radio Cellular band
Microwaves Radar, Wi-Fi
Millimeter waves, Telemetry
Infrared
Visible light
Ultraviolet
X-rays Gamma rays
10^5 10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 Hz
Low Energy
High Energy
Wavelength about 300 m (3 football fields)
Wavelength about 3 m (10 feet)
Wavelength about 3 cm (1 inch)
Wavelengths 400–700 nm (violet) (red)
Wavelength about 30x the diameter of a hydrogen atom
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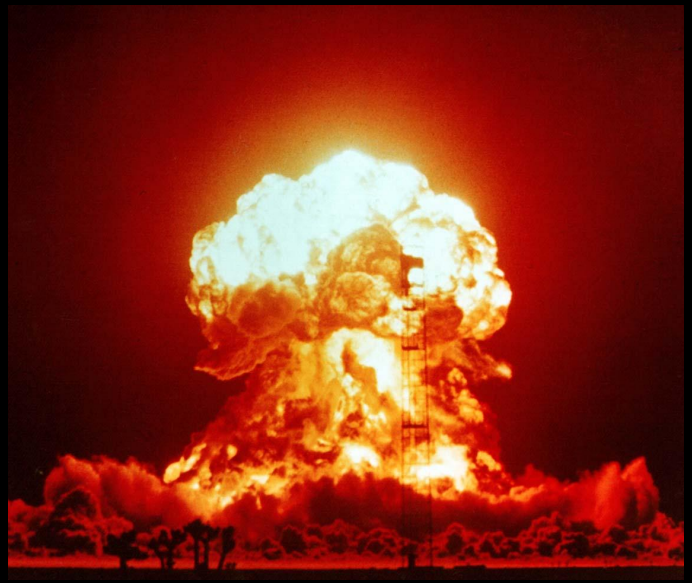

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

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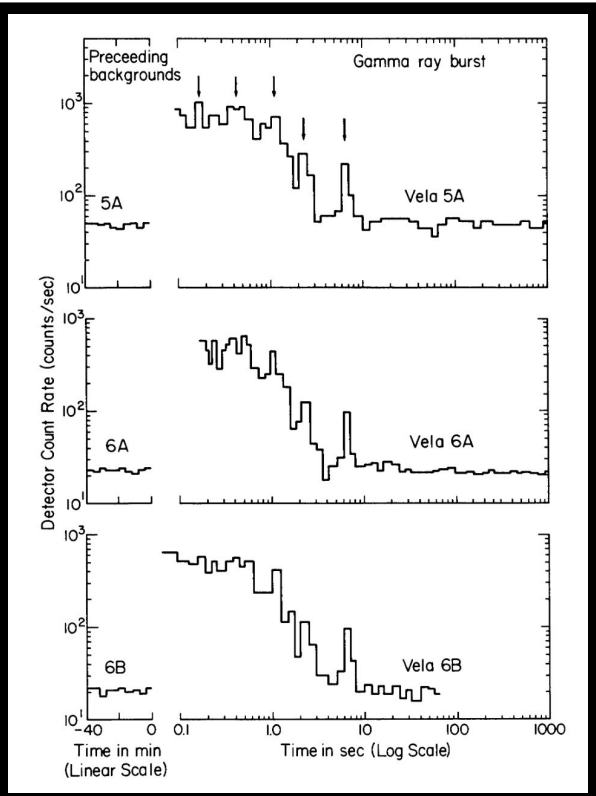


Not consistent with Nuclear explosion...

Not from the Earth, Sun, or Solar System...

The mystery of GRBs is born!

What could they be?!

Proposed theories:

- Meteors hitting neutron stars
- Neutron star ‘glitches’
- Cosmic strings
- Black hole ‘eruption’
- ...and more!

The only feature that all but one (and perhaps all) of the very many proposed models have in common is that they will not be the explanation of GRBs.” - Malvin Ruderman (1974)

Chapter Two

Hunting for More Data and the Last Great Debate in Astrophysics

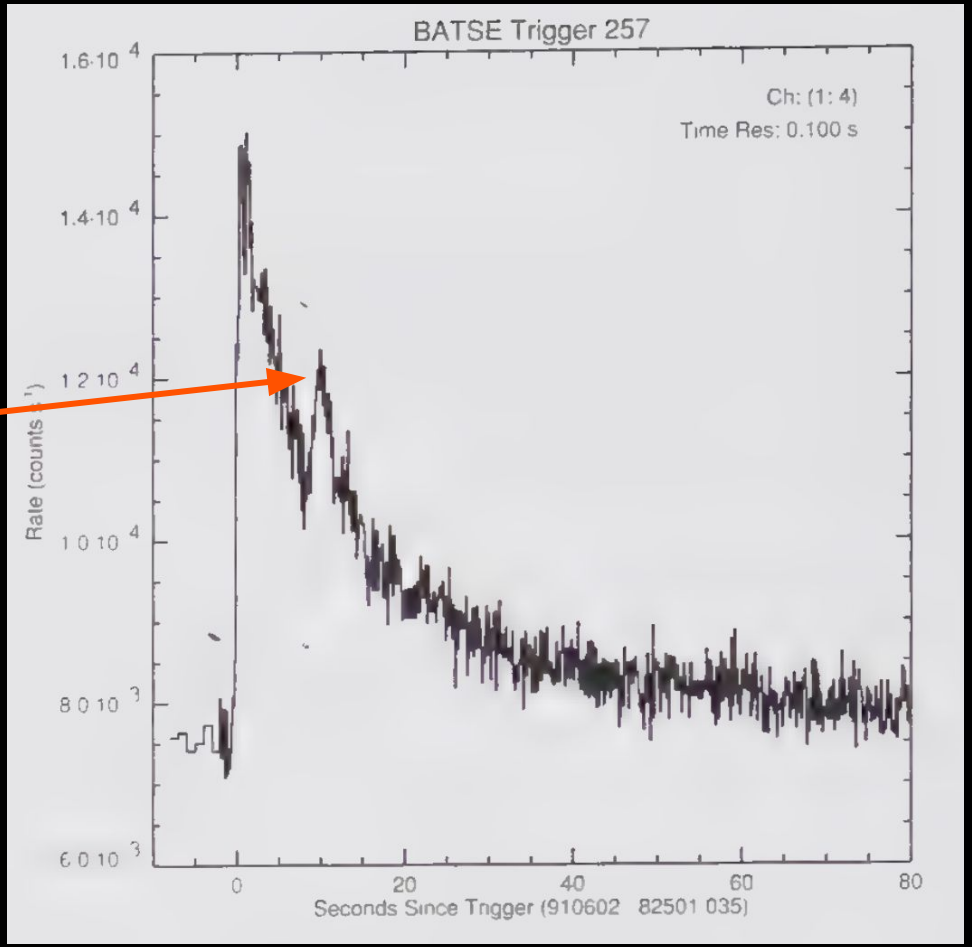
‘Burst And Transient Source Experiment’ (BATSE)

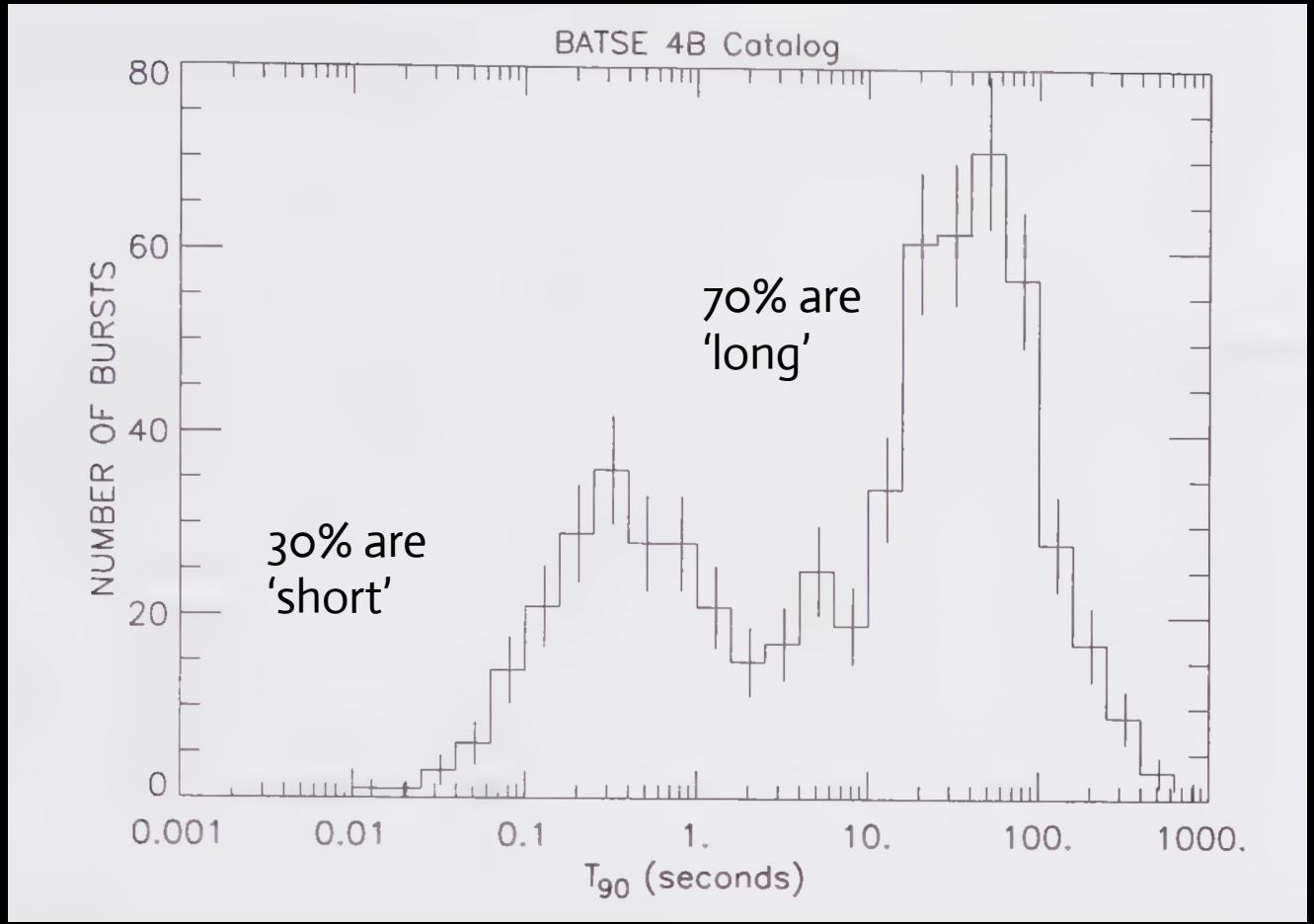
~2700 GRBs detected from 1991-2000

About 1 burst per day

What we saw..

Source must be small, less than ~300 km





Two distinct classifications start to appear with new data, short and long GRBs.

...different mechanisms?

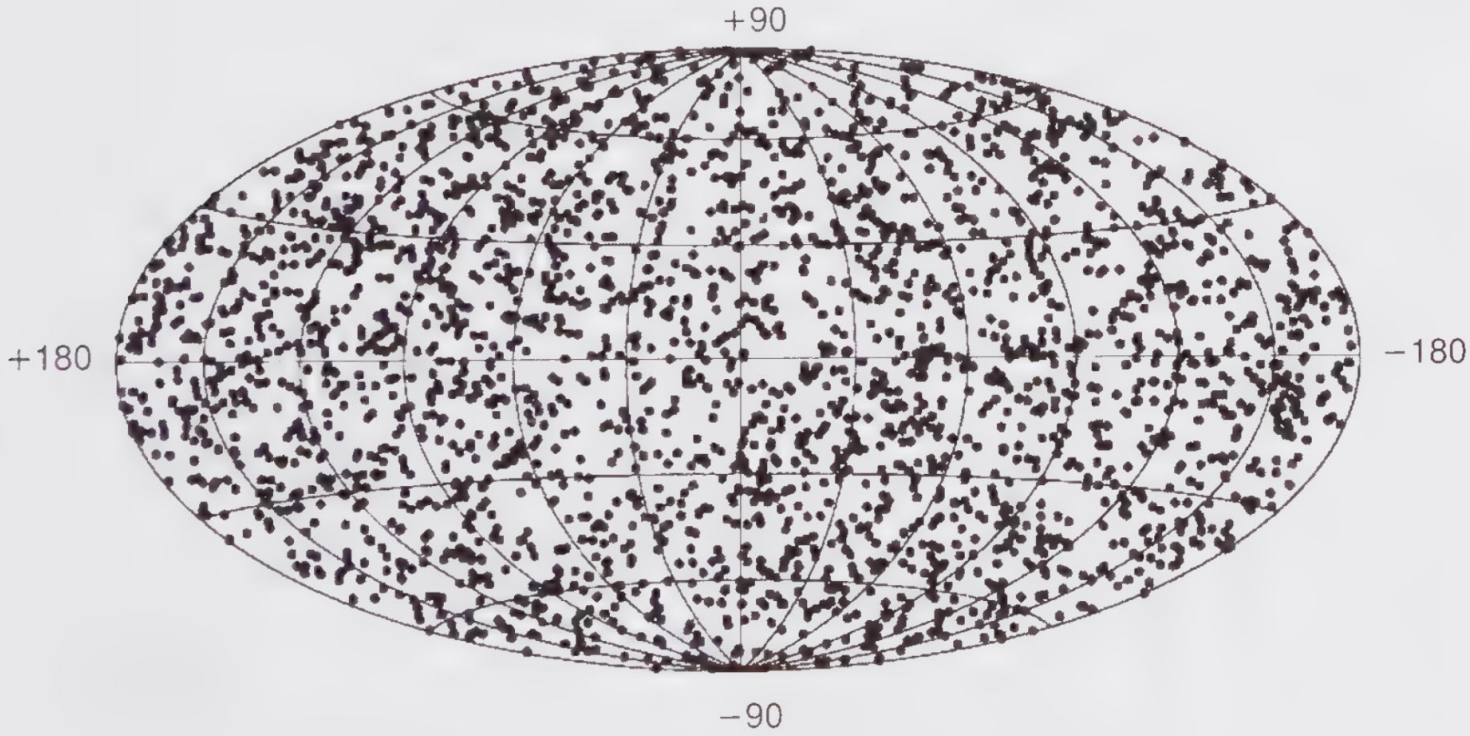


Figure 7.1 Distribution of 2704 gamma-ray bursts on the sky as found by BATSE. The Galactic plane corresponds to the central horizontal line. Courtesy of the Gamma-Ray Astronomy Team at the National Space Science and Technology Center (NSSTC); see http://gammaray.nsstc.nasa.gov/.

GRBs are...

- From small sources
- Distributed randomly across the sky
- Either ‘short’ or ‘long’, likely different sources
- Highly energetic

$$E_{\rm iso} = 4\pi d^2 f \sim \begin{cases} 2 \cdot 10^{40}\ {\rm erg}, & {\rm for}\ d = 15\ {\rm kpc} \\ 2 \cdot 10^{41}\ {\rm erg}, & {\rm for}\ d = 50\ {\rm kpc} \\ 2 \cdot 10^{51}\ {\rm erg}, & {\rm for}\ d = 5\ \ {\rm Gpc} \end{cases} .$$

Two Camps Emerge...

Galactic origin!

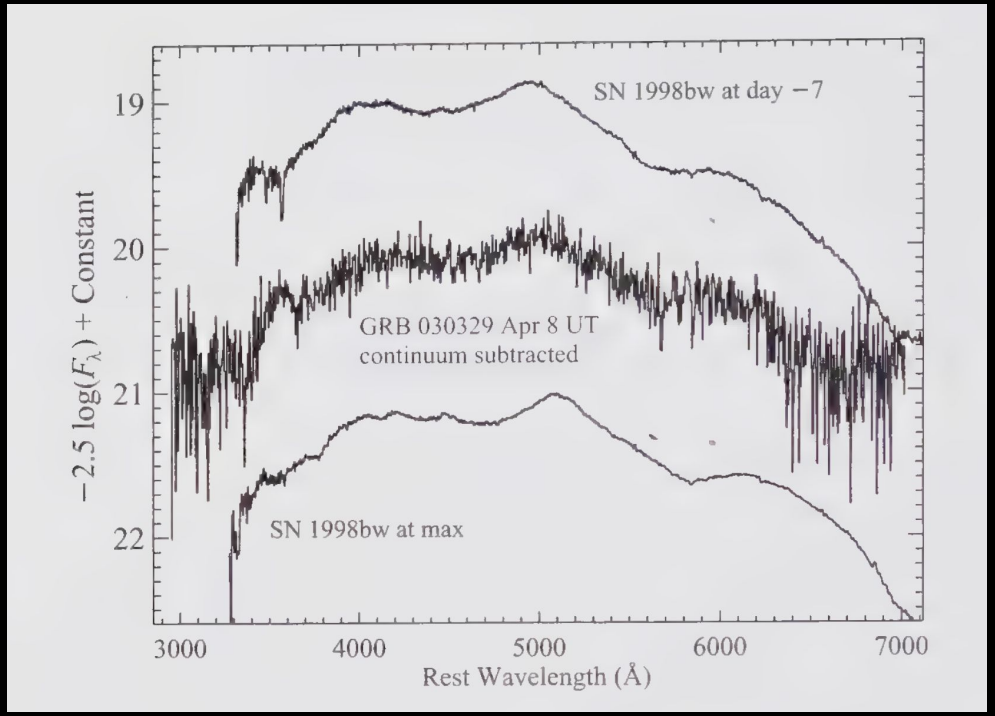
Don Lamb

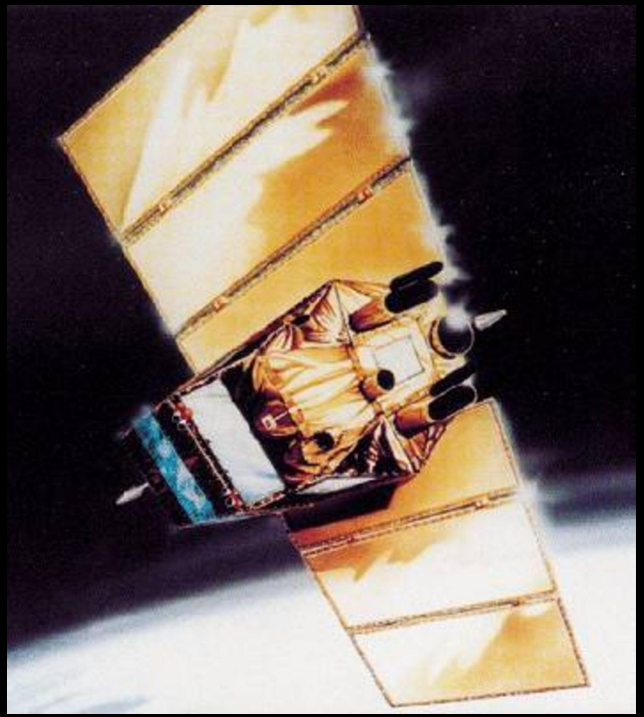
Cosmological origin!

Bogdan Paczynski

1995: The Great Debate in NYC

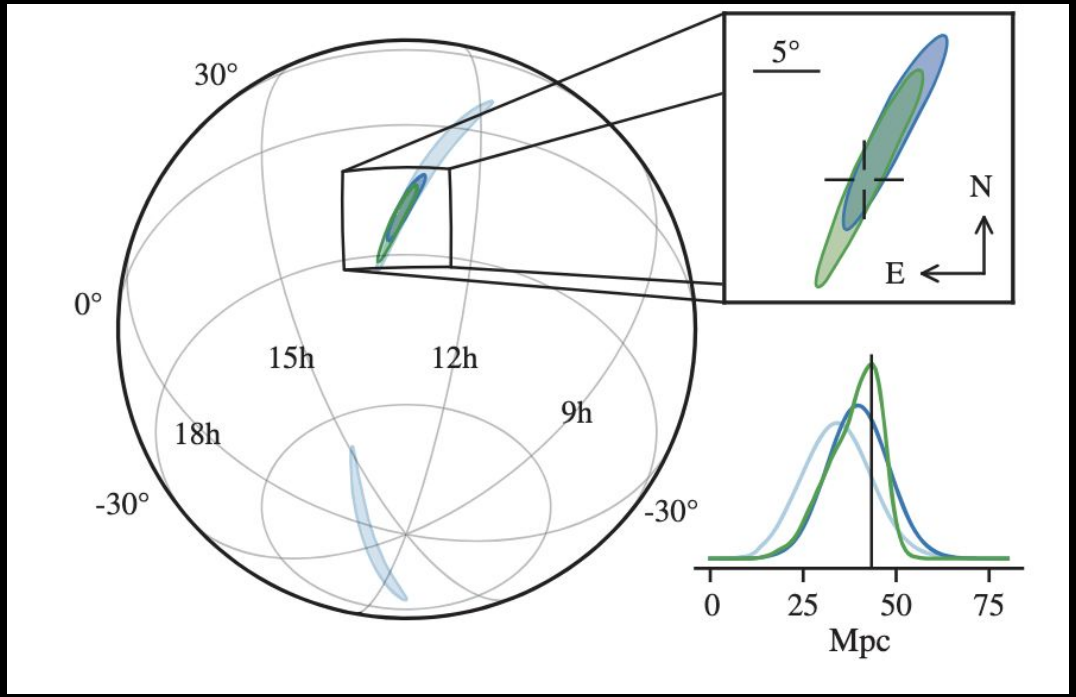
The Smoking Gun: Linking a GRB to a SNe

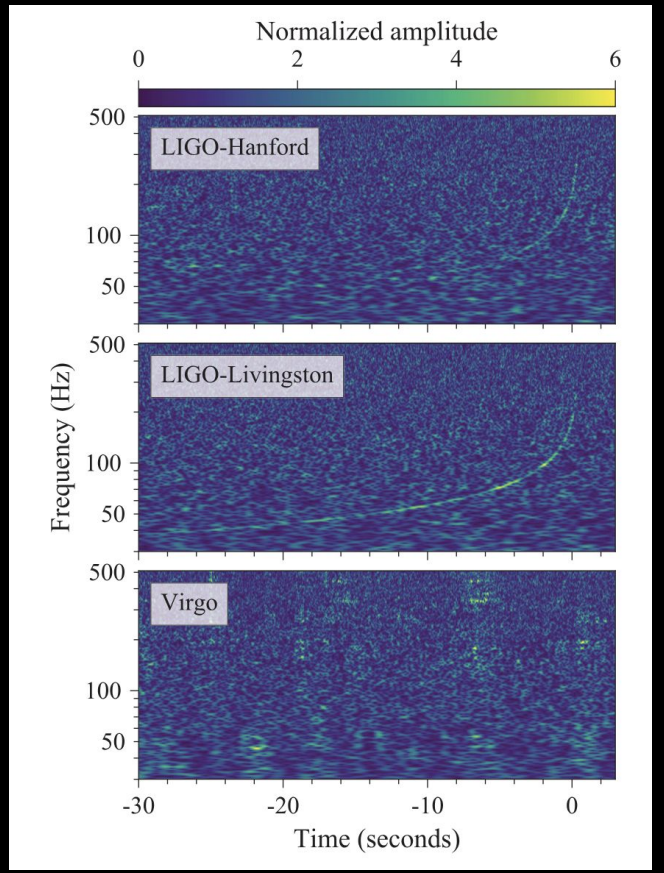




BeppoSAX

GRB 170817A linked to GW 170817

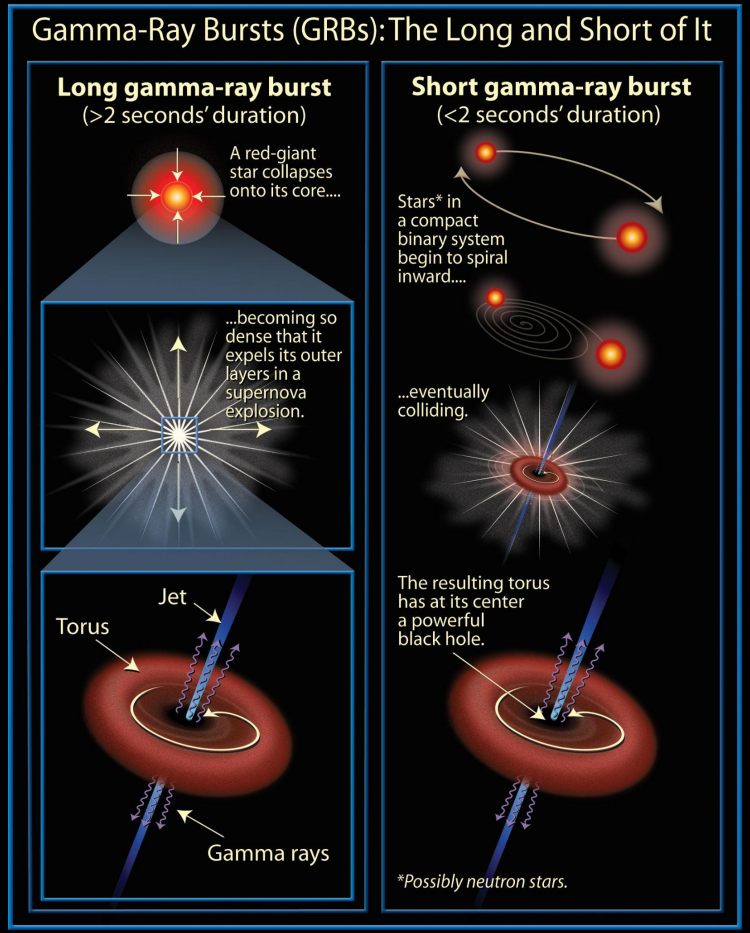




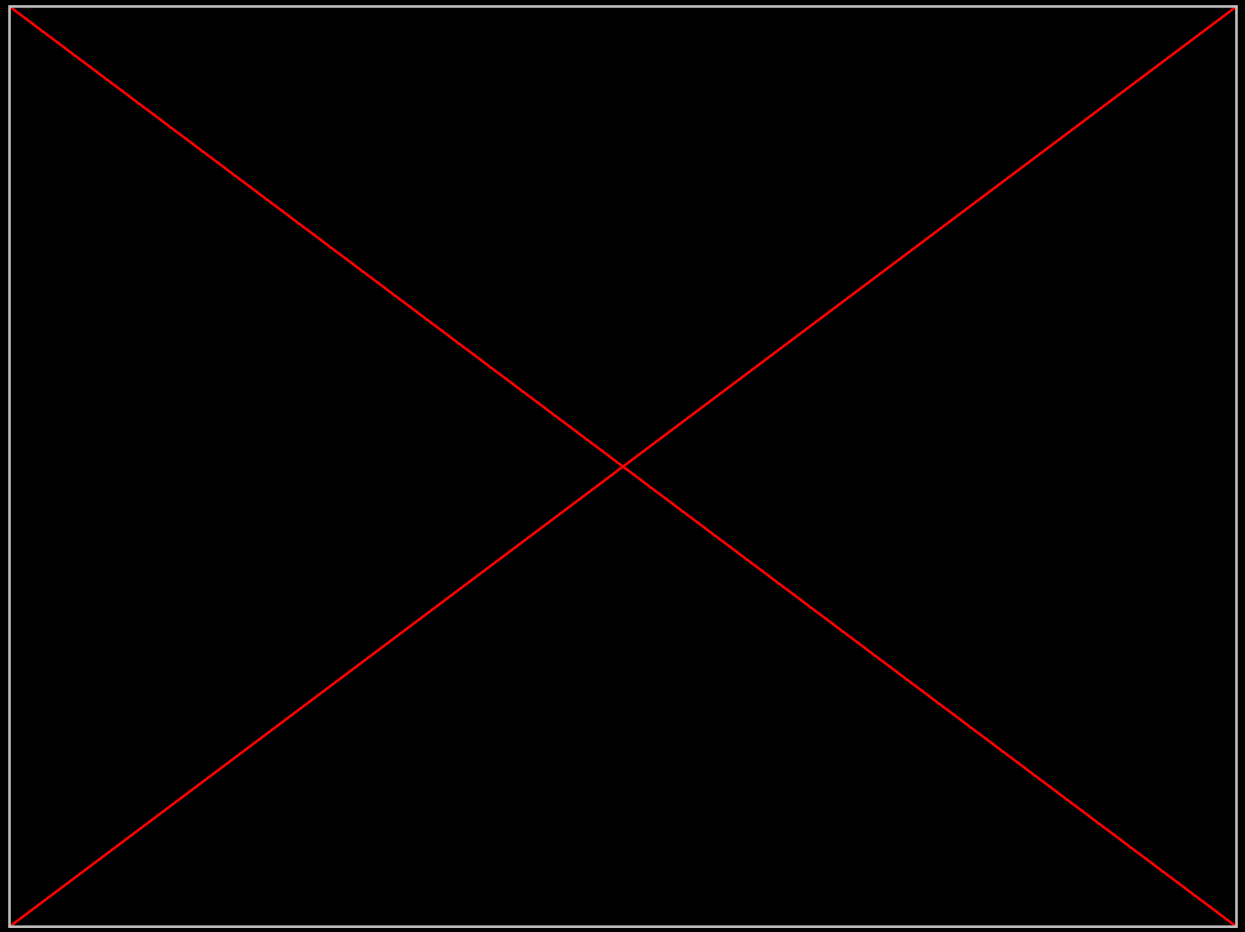
Chapter 3: The Long and Short of GRBs

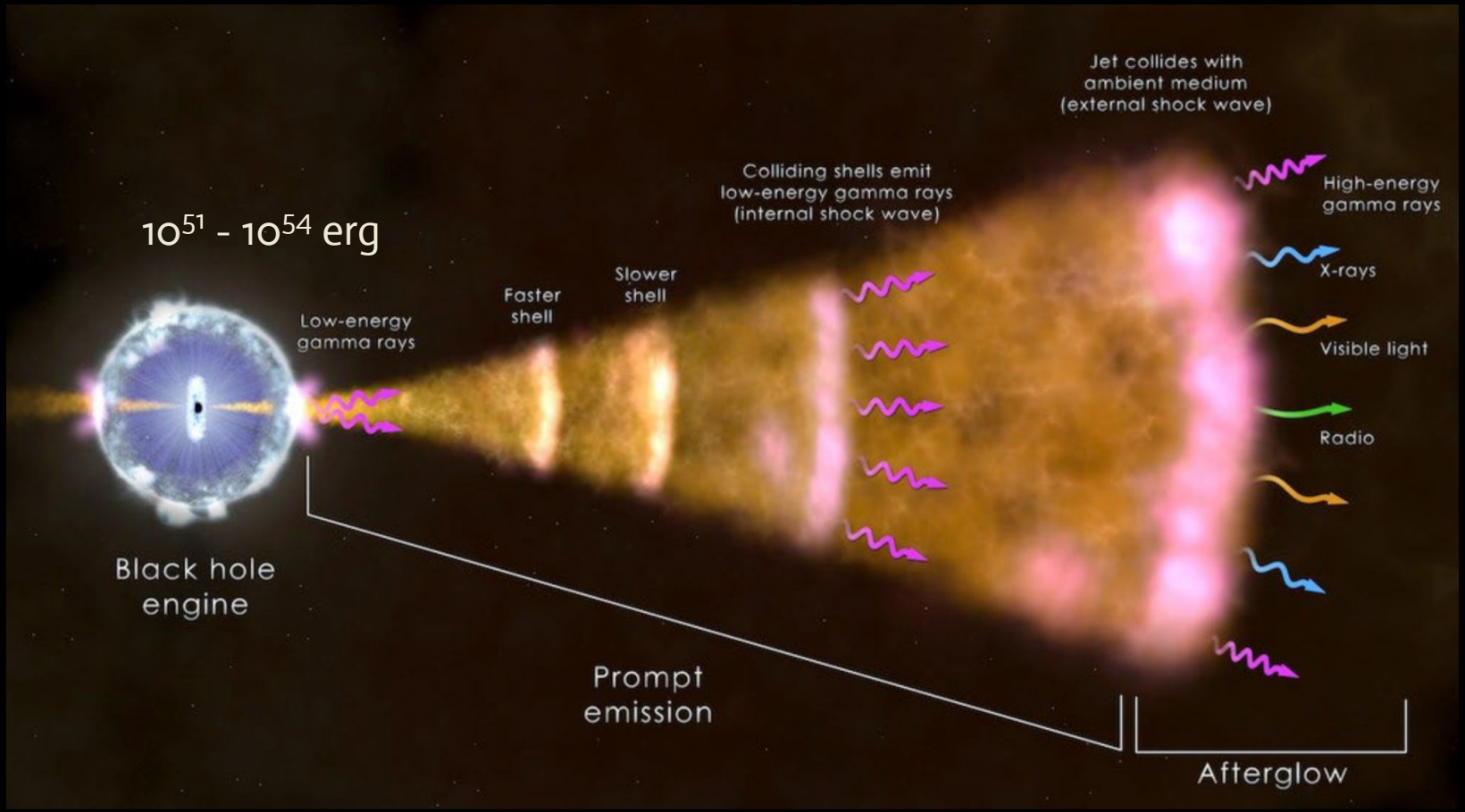
Property	Long GRB	Short GRB
Duration	~ 30 s	~ 0.3 s
Observed rate (BATSE)	$\sim 500\,\mathrm{yr}^{-1}$	$\sim 170\,\mathrm{yr}^{-1}$
Variability timescale	~ 1 ms	~ 1 ms
Host galaxy	Galaxies with active star formation	Galaxies with and without star formation
Supernova?	Confirmed in some cases	Prob. not
Isotropized γ-energy $E_{\gamma,\mathrm{iso}}$	$\sim 10^{53}$ erg	$\sim 10^{50}$ erg
Median redshift	~ 2	~ 0.3
Popular model	"collapsar"	Compact binaries

Long GRBs–
Massive star
collapse,
forms black
hole



Short GRBs –
Merging of
compact objects




10^{51} - 10^{54} erg
Low-energy gamma rays
Faster shell
Slower shell
Colliding shells emit low-energy gamma rays (internal shock wave)
Jet collides with ambient medium (external shock wave)
High-energy gamma rays
X-rays
Visible light
Radio
Black hole engine
Prompt emission
Afterglow

Nuclear Test Ban Treaty, Vela Satellites Launched

1963

1967

First GRB detected

Results made public

1973

1991

BATSE begins

Debate held in NYC

1995

1997/98

Long GRBs linked to SNe

Short GRB linked to merger

2017

lapeer.github.io
dlapeer@umass.edu